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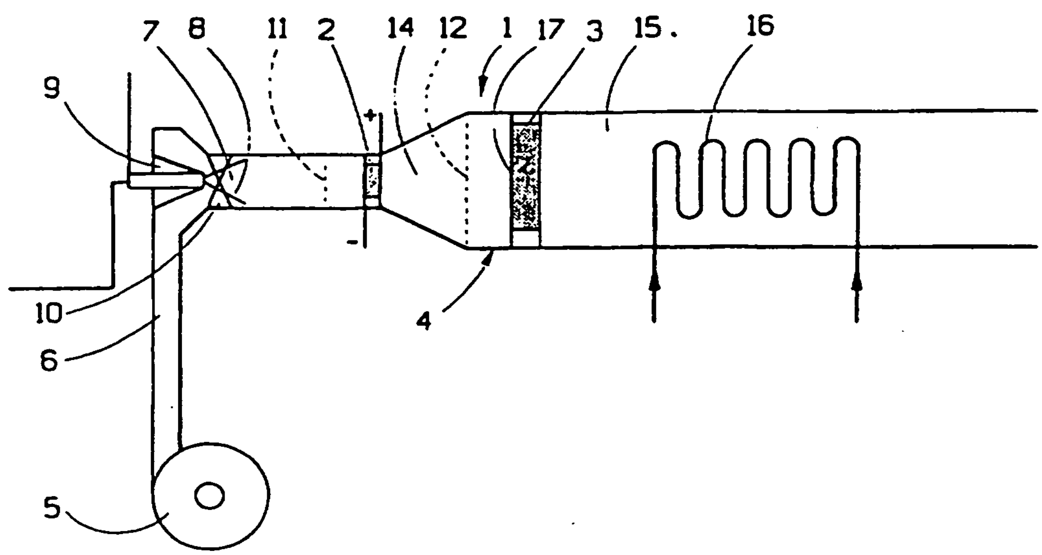

(57) Abstract

The invention relates to a method of igniting and controlling a catalytic combustor (1), wherein the combustor comprises a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), wherein the first catalytic reactor (2) is heated to a temperature which exceeds or is equal to the ignition temperature of the first catalytic reactor (2), whereafter a mixture (8) of fuel and air is introduced to the catalytic reactor (2), whereby catalytic combustion is started in the first catalytic reactor (2). The mass flow through the catalytic combustor (1) is increased after ignition of the first catalytic reactor (2), whereafter combustion of the fuel/air mixture (8) partly takes place in gas phase in an intermediary chamber (14) between the first catalytic reactor (2) and the second catalytic reactor (3). The invention also pertains to a combustor (1) and its use for heating in a vehicle.

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CATALYTIC COMBUSTION CHAMBER AND METHOD FOR IGNITING AND CONTROLLING THE CATALYTIC COMBUSTION CHAMBER

TECHNICAL FIELD:

The invention pertains to a method for igniting and controlling a catalytic combustor, wherein the combustor comprises a first catalytic reactor and at least a second catalytic reactor arranged in series with the first catalytic reactor, wherein the first catalytic reactor is heated to a temperature which exceeds or is equal to the ignition temperature of the catalytic reactor which is the temperature at which a 50% conversion rate is achieved in the catalytic reactor, whereafter a mixture of fuel and air is introduced to the catalytic reactor, whereby catalytic combustion is started in the first catalytic reactor.

Further, the invention relates to a method for igniting a catalytic reactor and a catalytic combustor comprising at least two serially arranged catalytic reactors.

BACKGROUND:

In order to achieve efficient combustion in a combustor even at low temperatures and to avoid emission of high amounts of nitric oxides, it has been suggested that the combustion is performed in the presence of a catalyst. By using a catalyst it is possible to achieve almost complete combustion of fuel/air-mixtures in which the percentage of fuel is very low. This implies that catalytic combustors are very safe since the gas mixture which is used is not inflammable at atmospheric pressure in the absence of a catalyst. Accordingly, there is no risk of explosion if the air/fuel-mixture should leak out of the catalytic combustor. In addition, a catalytic combustor is reliable and does not generate irritating noise when in operation.

In Japanese patent application no. 2-197245 a catalytic combustor is described comprising two catalytic reactors, wherein a main catalytic reactor is heated by the exhaust gases from a preheating catalytic reactor. The preheating catalytic reactor is heated to its ignition temperature by means of an electrically heated heater. A part of the heat generated by combustion in the preheating catalytic reactor is utilized for heating a carburettor in order to vaporize the fuel. An ignition process of this type is comparatively slow, requires a large initial consumption of electricity and results in high emissions of carbohydrates and carbon monoxide.

A further catalytic combustor comprising two serially coupled catalytic reactors is described in Japanese patent application no. 60-27994. This publication also utilizes a two-step process for starting catalytic combustion. Instead of heating the first catalytic reactor when igniting the catalytic combustor, the gas which is conducted through the catalytic reactor is heated, thereby accomplishing ignition. An ignition process of this type demands high initial energy supply and, consequently, involves large energy consumption during the ignition process.

These previously known two-step ignition processes do not to a sufficiently high extent diminish either the emissions of incompletely combusted fuel or the consumption of electricity during the ignition process. For this reason, a demand for a simple, quick and electricity saving ignition process for a catalytic combustor having low emission of carbohydrates and carbon monoxide still remains.

The present invention offers an ignition process of the kind mentioned in the introduction. The process according to the invention is primarily distinguished by the fact

that the mass flow through the catalytic combustor is increased after ignition of the first catalytic reactor, whereafter combustion of the fuel mixture partly takes place in a gas phase in an intermediary chamber between the first catalytic reactor and the second catalytic reactor.

In accordance with a preferred embodiment the gas phase combustion generates a flame which heats the end surface of the second catalytic reactor being closest to the first catalytic reactor to a temperature which exceeds or is equal to the ignition temperature of the second catalytic reactor, which is the temperature at which a 50% conversion rate is obtained in the second catalytic reactor, whereafter the mass flow through the catalytic reactor is adjusted so that substantially all combustion takes place in the second catalytic reactor and combustion in the first catalytic reactor and in the gas phase substantially ceases.

It is suitable if the end surface of the second catalytic reactor being closest to the first catalytic reactor is heated to a temperature which exceeds or is equal to the ignition temperature before the mass flow through the catalytic reactor is changed.

In accordance with the invention, it is advantageous if the first catalytic reactor is ignited after heating to its ignition temperature by being charged with a fuel/air-mixture having a λ-value exceeding 1, whereby catalytic combustion is started in the catalytic reactor and whereby the temperature in the catalytic reactor is caused to rise further above the ignition temperature, whereafter the λ-value is raised by increasing the air mass flow through the catalytic reactor at a catalytic reactor temperature corresponding to from 60% to almost 100% conversion in the catalytic reactor.

The gas phase combustion in the intermediary chamber may be achieved by increasing the mass flow through the first catalytic reactor at a constant λ-value, after ignition of the first catalytic reactor. When flame combustion takes place in the intermediary chamber, the major part of the combustion is preferably performed in the gas phase after the first catalytic reactor. This is accomplished by controlling the λ-value. In this manner, a lean catalytically stabilized gas phase combustion is obtained, resulting in low nitrogen oxide emission, something that would not be possible without the presence of the catalyst.

Very lean air/fuel-mixtures (high λ-values) produce a combustion without a flame while too rich air/fuel-mixtures (low λ-values) produce a conventional flame combustion resulting in high emissions of nitrogen oxides. Accordingly, it is important to adjust the λ-value so that the desired combination of catalytical combustion and gas phase combustion is obtained.

The preheating of the first catalytic reactor is preferably performed electrically, though conventional heating with a flame is conceivable.

A catalytic combustor in accordance with the invention, comprising a first catalytic reactor and at least a second catalytic reactor serially arranged with the first catalytic reactor is distinguished by the ratio between the volume of the first catalytic reactor and the volume of the second catalytic reactor being 4.5×10^{-3} - 0.18 and preferably 0.016 - 0.05.

In accordance with one embodiment, a static mixer is located upstream of the first catalytic reactor.

In accordance with another embodiment, a first flow-equalizing and mixing net is located upstream of the first catalytic reactor. If the catalytic combustor comprises both a static mixer and a flow-equalizing net, the flow-equalizing net is suitably arranged between the mixer and the first catalytic reactor.

In accordance with still another embodiment, a second flow-equalizing net is located between the first catalytic reactor and the second catalytic reactor.

In order to evaporate the fuel and increase the efficiency of a heat exchanger which is connected to a catalytic combustor, a conduit for returning a part of the exhaust gas from the catalytic combustor to an air blower for supplying the combustor with air may be arranged downstream of the second catalytic reactor, between the combustor and the inlet to the air blower.

Another way of vaporizing the fuel and increasing the efficiency of a catalytic combustor is by conducting the air to the air blower through a heat exchanger which is arranged downstream of the second catalytic reactor.

The catalytic combustor in accordance with the invention may further be provided with a peltier element arranged in connection with the second catalytic reactor for retrieving electrical energy.

The invention further includes a method for controlling the ignition process of a catalytic reactor. The method is distinguished by a mixture of fuel and air having an initial λ-value exceeding 1 being introduced to the pre-heated catalytic reactor whereby catalytic combustion is started in the catalytic reactor and whereby the temperature in the catalytic reactor is caused to rise

further above the ignition temperature, whereafter the λ-value is increased to a second λ-value exceeding the initial λ-value by increasing the mass flow through the catalytic reactor at a temperature in the catalytic reactor corresponding to between 60% and almost 100% conversion in the catalytic reactor. The initial λ-value is preferably between 1 and 2 and the second λ-value is preferably between 2 and 4.

By adjusting the gas flow and the relative air/fuel ratio (the λ-value) through the first catalytic reactor so that a part of the combustion takes place in a gas phase after the first catalytic reactor, it is possible to obtain rapid and efficient heating, resulting in a faster ignition of the second catalytic reactor. In this manner the ignition time, as well as the energy consumption during the ignition process, may be reduced to a minimum.

The power which is produced in the flame between the two catalytic reactors is considerably higher than the power which may be produced in the first catalytic reactor at 100% catalytic combustion. This implies that, due to the flame between the catalytic reactors, it is possible to increase the power of the first catalytic reactor approximately 3 times as compared to combustion taking place completely in the first catalytic reactor and not at all in a gas phase. Hereby, it is possible to reduce the size of the first catalytic reactor which implies less consumption of electricity during the ignition process and a reduced pressure fall over the catalytic reactor during operation. The latter fact implies that the electricity consumption in the blower supplying the combustor with air is reduced.

Another effect, resulting from the first catalytic reactor being of a considerably smaller size than in previously

known catalytic combustors, is that the total flow through the catalytic reactor is low during start-up. This means that the amount of carbohydrates and carbon monoxide which is emitted during the start-up process is minimal.

The reduced emission of uncombusted fuel is additionally due to the ignition process being optimized by the control of the λ-value during the different ignition steps. In particular, the emission of carbohydrates and carbon monoxide is reduced.

The ratio between the amount of air and fuel being supplied to the catalytic combustor is specified as the so called λ-value. The λ-value is a measure of the relative air/fuel ratio and constitutes the ratio between the real air/fuel ratio and the stoichiometric air/fuel ratio.

Low λ-values mean a "rich" fuel mixture with a large proportion of fuel in relation to the amount of air, while a high λ-value means a "lean" air/fuel mixture with relatively much air in the mixture.

In connection with motor vehicles, for instance cars, it has been increasingly more common to provide these with a car heater and/or an engine pre-heater. By using car heaters and engine pre-heaters, several advantages are achieved. One advantage is, of course, that it is possible to increase the comfort of the user of the vehicle by pre-heating the air in the vehicle to a pleasant temperature. Another advantage is that pre-heating of the engine in a motor vehicle reduces the initial fuel consumption as well as the emission of incompletely combusted fuel during the start-up process.

In addition, the exhaust gases from the heater may be conducted into the inlet side of the engine, resulting in

an easier and cleaner cold start of the engine at low temperatures. At a high λ-value, a large quantity of oxygen gas remains in the exhaust gas from the car heater, permitting the inlet air to contain a large proportion of heater exhaust gas.

A catalytic combustor in accordance with the invention is eminently suited for use in engine pre-heaters and heaters for motor vehicles. The low power consumption, the clean start and silent operation, as well as operational reliability, controllability and explosion safety are some of the advantages which carry particularly heavy weight.

Furthermore, it is possible to use a combustor in accordance with the invention for power and heat production for several other purposes. It may, for instance, be used as a combustor in Sterling engines and gas turbines or for heating buildings. In the latter case, it is possible to use the flow of exhaust gas from the combustor for direct heating, due to the fact that the emissions of carbohydrates, carbon dioxide and nitrogen oxides are very low, both during ignition of the combustor and during operation. A particular advantage is thereby obtained when using a combustor in accordance with the invention for heating of greenhouses, since the carbon monoxide which is produced during combustion may be used instead of the carbon dioxide which has to be supplied separately to the greenhouse air when using conventional heating.

The combustor in accordance with the invention has very good controllability. By adjusting the λ-value, the temperature can be controlled. By lowering the λ-value, the temperature is raised while a raised λ-value gives a lower temperature. In a corresponding manner, the power in a catalytic reactor may be controlled by changing the temperature at a constant mass flow through the catalytic

reactor. This is achieved by injecting more fuel at the same air flow, whereby the λ-value is lowered and the temperature is raised.

During ignition, the λ-control is used to increase the temperature of the catalytic reactor and thereby the speed of heating the reactor. In this manner, a very clean start-up process is obtained with negligible emission of nitrogen oxides, carbohydrates and carbon monoxide.

The high degree of controllability also lowers the total emission of carbohydrates and carbon monoxide during operation, since the broad controllable range means that shutdown and restart at low power can be avoided.

Since only either the air flow or the fuel injection needs to be altered in order to achieve a temperature change over a fairly broad range it is comparatively simple to control and adjust the temperature in the catalytic reactors. Conventional flame combustors are extremely limited in their controllability, since the flame goes out when using lean fuel mixtures. As a contrast, a combustor in accordance with the invention exhibits high operational reliability, since the combustor is less susceptible to unwanted variations in the λ-value during operation.

BRIEF DESCRIPTION OF FIGURES:

The invention will in the following be described in detail with reference to the Figs. which are shown in the appended drawings, wherein:

Fig. 1 is a schematic representation of a two-step catalytic combustor in accordance with the invention;

Fig. 2 shows the catalytic combustor of Fig. 1 with two variants of recycling of heat from the exhaust gases from the combustor.

DESCRIPTION OF EMBODIMENTS:

The combustor 1 which is shown in Fig. 1 comprises a first catalytic reactor 2, the catalytic ignition reactor, and a second catalytic reactor 3, the main catalytic reactor. The two catalytic reactors 2,3 are mounted serially inside a pipe-shaped casing 4.

Both catalytic reactors 2,3 are so called monoliths which implies that each catalytic reactor 2,3 consists of a single, continuous carrier material having a catalyst arranged on the surface. Usually, a monolith has the shape of a hollow, elongated body with a plurality of penetrating channels extending in the longitudinal direction of the body. An advantage associated with a monolithic catalytic reactor is that the pressure fall over the catalytic reactor is very small. This is a significant difference over other types of catalytic reactors such as, for instance, pellet beds.

The combustor 1 is supplied by a mixture of air and fuel. The air is thereby conducted from an air blower 5 by way of an air duct 6 to the inlet 7 of the combustor. In the inlet 7 the air is mixed with atomized fuel 8 which is injected from a fuel injector 9. In order to accomplish an even mixture, a static mixer 10 is located in the inlet 7 to the catalytic combustor 1. In addition, a first flow-equalizing and mixing net 11 is located upstream of the static mixer 10, between this and the catalytic ignition reactor 2 in order to achieve further homogenization of an air/fuel flow through the combustor 1 as well as small scale turbulence

which results in better mixing and thereby favourable combustion in a catalytic reactor.

In order to achieve good mixing in the static mixer 10, it is suitable if the mixer 10 has the shape of a propeller wherein the angle of the blades in relation to an axial centre line through the combustor 1 is greater at the central part of the mixer 10 than at its periphery. Accordingly, some examples of angles which may be used are a first angle of 40° at the central part of the mixer 10 and a second angle of 25° at the peripheral part of the mixer.

A suitable design of the flow equalizing net 11, giving the desired micro turbulence and flow equalization in a fuel mixture after passage through the net, is a net wherein the ratio between the diameter of a net mesh and the diameter of a filament in the net, $D_{mesh}: D_{filament} = 3-4.6$.

The mixing devices which have been described are, of course, only intended as examples of mixing devices which provide satisfactory mixing of the air/fuel flow. Consequently, other types of mixers which provide the desired result may be used.

A second flow equalizing net 12 is mounted between the catalytic ignition reactor 2 and the main catalytic reactor 3 in order to create an even flow profile after the catalytic ignition reactor 2. The second flow equalizing net 12 is arranged in a cone-shaped intermediate chamber 14 which is delimited by the two catalytic reactors 2,3 and the surrounding combustor casing 4.

The outlet 15 of the main catalytic reactor 3 is connected to a heat exchanger 16 in which the thermal energy from the flow of exhaust gas from the combustor 1 is absorbed.

An alternative way of extracting the heat which is generated in the reaction in the main catalytic reactor 3 is to give the carrier material of the main catalytic reactor 3 the shape of a heat exchanger. In this manner, no separate heat exchanger 16 needs to be mounted after the main catalytic reactor.

The length of the catalytic ignition reactor 2 in the direction of the mass flow and expressed as a part of the diameter D of the catalytic reactor is suitably between

1/2 x D and 1/90 x D

and preferably between

2/15 x D and 2/45 x D.

The relation between the volume of the catalytic ignition reactor 2 and the volume of the main catalytic reactor 3 is suitably approximately 4.5×10^{-3} - 0.18 and preferably 0.016 - 0.05. Instead of conventional monolithic catalytic reactors it is possible to use catalytic reactors in the shape of a net. In particular, the catalytic ignition reactor 2 may be a net with the advantage of requiring little space in a construction. When catalytic reactors in the form of a net are used, it is, however, not meaningful to specify the ratio between the volume of the smaller catalytic reactor and the larger catalytic reactor.

In order to achieve efficient heating of the end surface 17 of the main catalytic reactor 3 being closest to the catalytic ignition reactor 2, it has been found to be suitable to arrange the main catalytic reactor 3 at a distance x mm from the catalytic ignition reactor 2, where:

$D_2x/D_3 = 27 - 72.$

where D_2 = is the cross-sectional diameter of the catalytic ignition reactor and D_3 = is the cross-sectional diameter of the main catalytic reactor.

The distance between the catalytic reactors is chosen so that a rapid and even heating of the main catalytic reactor 3 is obtained, as well as an even flow profile during operation.

During ignition of the combustor, a voltage is applied to the catalytic ignition reactor 2 from an energy source which is not shown in the drawings, whereby the resistance in the material causes the catalytic ignition reactor 2 to be heated to a temperature exceeding the ignition temperature of the catalytic ignition reactor 2. The temperature of a catalytic reactor may be determined by measuring the resistance in the catalytic reactor which is temperature-dependent. The resistance can be measured by using the heating current or another current which is applied. Alternatively, an ordinary temperature gauge may be used.

A mixture of air and fuel 8 is led through the static mixer 10 and the first flow equalizing net 11 and thereafter passes through the catalytic ignition reactor 2. The mixture 8 of air and fuel is obtained by atomizing fuel, such as gasoline or diesel, in an injection valve at a differential pressure of approximately 3 bar and injecting the atomized fuel from the injector 9 and mixing it with air from the air blower 5. When the fuel mixture 8 reaches the heated catalytic ignition reactor 2, combustion is started in the catalytic ignition reactor 2. Due to the combustion process, the temperature in the catalytic ignition reactor 2 is subsequently increased by increasing the amount of air in the air/fuel mixture 8. Now 100% of

the combustion takes place in the catalytic ignition reactor 2.

Thereafter, the mass flow is increased further at a constant λ-value. The increased mass flow implies that combustion no longer takes place only in the catalytic ignition reactor 2, but that part of the fuel is combusted in gas phase in the intermediary chamber 14 between the catalytic ignition reactor 2 and the main catalytic reactor 3. Preferably, the greater part of the combustion takes place in the gas phase in the intermediary chamber 14, the remaining combustion still being effectuated in the catalytic ignition reactor 2.

Through the gas phase combustion a flame is produced after the catalytic ignition reactor 2. The flame rapidly heats the end surface 17 of the main catalytic reactor which is closest to the flame to the ignition temperature of the main catalytic reactor 3. In order to secure an even heating of all of the end surface 17 of the main catalytic reactor 3, as well as an even flow profile during operation, the second flow equalizing net 12 is, as has been previously mentioned, arranged between the two catalytic reactors 2,3. When the surface temperature of the main catalytic reactor 3 exceeds or is equal to the ignition temperature of the catalytic reactor 3, the mass flow is increased once again by increasing the amount of air in the air/fuel-mixture, whereafter the mass flow is further increased. Due to the increased mass flow, the combustion process is gradually transferred from the catalytic ignition reactor 2 and the gas phase to the main catalytic reactor 3 and the combustion in the combustor 1 changes from a start-up state to an operational state.

The exhaust gases which are produced by combustion in the main catalytic reactor 3 are led through the heat exchanger

16, whereby the heat content of the exhaust gases can be used for heating purposes, for instance in an engine heater or a vehicle heater in a motor vehicle.

In order to increase the efficiency of the system, a small portion of the warm exhaust gases from the main catalytic reactor 3 may be recirculated through a conduit 19 between the space after the second catalytic reactor 3 and the air blower 5, as shown in Fig. 2. The recirculated flow of exhaust gas may thereby be used to achieve fuel vaporization. Furthermore, in Fig. 2 there is shown an alternative way of vaporizing the fuel and increasing the efficiency of the system by conducting the air to the air blower 5 through a second heat exchanger 20 which is mounted downstream of the previously described first heat exchanger 16. In this manner, the residual heat in the exhaust gas may be utilized for heating the air to the blower 5. The two systems which are shown in Fig. 2 do, of course, not have to be combined, but may used separately. In addition, it is possible to pre-heat the fuel to the combustor. Such pre-heating may be performed during the start-up process by using electricity or by using combustion heat. During operation, combustion heat is preferably used.

Moreover, the combustor 1 may be used to produce electrical energy by arranging a so called Peltier element on the surface of the main catalytic reactor 3 or on the heat exchanger 16. A Peltier element builds on the principle of creating a voltage differential between two metal surfaces having mutually different temperatures. By arranging one metal surface of the Peltier element on the outer surface of the catalytic reactor, it is consequently possible to convert part of the thermal energy which is produced in the catalytic reactor into electrical energy. In this manner,

the combustor is made self supporting and may be used as a support charger for connected systems.

EXAMPLE:

In order to further illustrate the invention, an ignition sequence for ignition of a combustor in accordance with the invention will be described in the following.

A catalytic combustor of the kind shown in Fig. 1 was used. Both catalytic reactors 2,3 were precious metal based monolithic catalytic reactors, i.e. catalytic reactors having a catalyst surface of platinum, palladium, or rhodium. The ratio between the volume of the catalytic ignition reactor 2 and the volume of the main catalytic reactor 3 was 0.041. The cell density of the catalytic reactors was 400 cells/sq.inch calculated over the cross-sectional area of each catalytic reactor. The ignition temperature of the catalytic reactors 2,3 was approximately 200°C. The ignition temperature of a catalytic reactor is defined as the temperature at which a conversion rate of 50% is achieved.

The catalytic ignition reactor 2 is electrically heated to 400°C. Thereafter, a mixture of fuel/air having a λ-value of 1.5 is introduced. At a surface temperature of the catalytic ignition reactor 2 of 900°C, λ is increased to 2.5 by increasing the air mass flow. All combustion thereby takes place in the catalytic ignition reactor 2. Thereafter the mass flow is further increased at a λ-value of 2.5, whereby a part of the combustion is transferred from the catalytic ignition reactor 2 and takes place in a gas phase in a flame which is produced in the intermediary chamber 14 between the catalytic ignition reactor 2 and the main catalytic reactor 3. When the surface temperature of the closest end surface 17 of the main catalytic reactor 3

reaches 400°C, the mass flow is further increased whereby all combustion is gradually transferred from the catalytic ignition reactor 2 and the flame in the intermediary chamber 14 to the main catalytic reactor 3. Thereby, the λ-value is 2.8. Stable and even operational combustion has now been reached.

The ignition temperatures and operational temperatures which have been given are chosen considering the catalytic reactors and the fuel which was used. However, the temperature does only to a comparatively limited extent depend on the type of fuel which is being used. Accordingly, when gasoline was used the temperature in the material of the catalytic reactors was approximately 1000°C, while the gas phase temperature was approximately 950°C.

The combustor will work even if the temperature is somewhat lower, or higher. The optimal temperatures are determined by weighing the speed of the ignition process against the power consumption during ignition. A higher pre-heating temperature, for instance 800°C further has the advantage that the start-up process is somewhat cleaner than at 400°C. However, since the start-up process only produces insignificant amounts of emissions, the increase in cleanliness which may be achieved at a higher pre-heating temperature is of no consequence for most applications. A lower pre-heating temperature has the advantage of lower energy consumption during the start-up process.

When using catalytic reactors other than the combination which has been described herein, the temperatures which are suitable for ignition and operation may, of course, be different from those which have been given herein.

As is evident from the above example, a high reaction rate is obtained within the ignition temperature range due to a low λ-value. As may be deduced from Diagram 1, the reaction rate is strongly dependent on temperature within this region, wherein a low λ-value results in a high reaction rate. In the region wherein the mass transport is limiting, the reaction rate is less dependent on temperature and is, instead, strongly dependent on mass flow. In this region the effect generation is increased by increasing the λ-value.

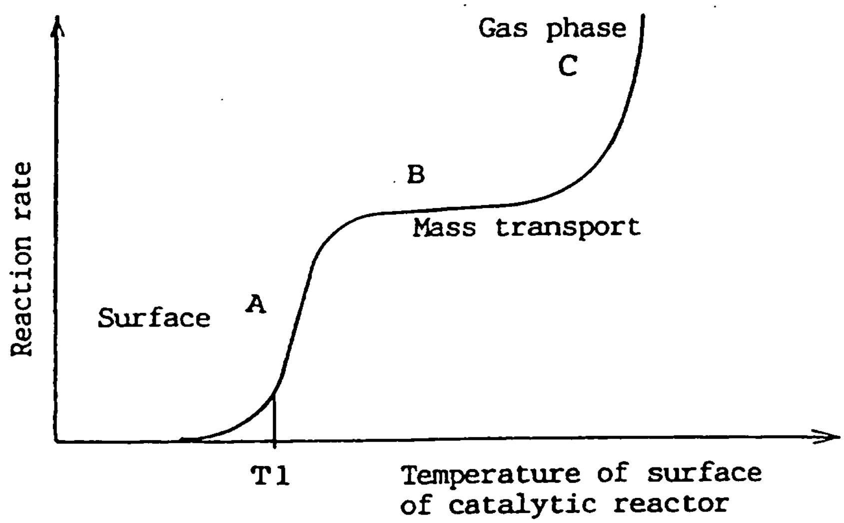

Diagram 1

At low temperatures, corresponding to the region A in the Diagram, combustion is started on the surface of the catalytic reactor. The reaction takes place only at the surface of the catalytic reactor and the temperature is close to the temperature in the reaction mixture. Within this region, the reaction rate is kinetically controlled. When the temperature reaches T1, corresponding to the ignition temperature of the catalytic reactor, the temperature is rapidly raised until the combustion reaches the mass transport limited region, marked B in the Diagram.

Due to the mass transfer limitation, the reaction rate within this region is only marginally dependent on the temperature. The concentration of fuel is very low near by the surface of the catalytic reactor and the temperature of the catalytic reactor is higher than the temperature of the mass flow through the catalytic reactor. At even higher temperatures, within region C in the Diagram, gas phase combustion is predominant and the reaction rate is exponentially increased.

The invention shall not be considered to be limited to the herein described example, but a plurality of further modifications and variants are conceivable within the scope of the appended claims.

It is, for instance, possible to use an ignition process wherein several serially arranged catalytic reactors are used to ignite a main catalytic reactor in a multi-step process.

Moreover, it is not necessary for the invention that the catalytic ignition reactor is electrically heated, instead conventional flame heating may be used.

In order to increase the power in the main catalytic reactor, it is possible to control the mass flow and the λ-value so that gas phase combustion is also obtained after the main catalytic reactor. This is a way to extract greater power from a catalytic reactor of a certain, predetermined size.

CLAIMS

1. A method of igniting and controlling a catalytic combustor (1), wherein the combustor comprises a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), wherein the first catalytic reactor (2) is heated to a temperature which exceeds or is equal to the ignition temperature of the first catalytic reactor (2), i.e. the temperature at which a 50% conversion rate is achieved in the catalytic reactor, whereafter a mixture of fuel and air is introduced to the catalytic reactor (2), whereby catalytic combustion is started in the first catalytic reactor (2), characterized in that the mass flow through the catalytic combustor (1) is increased after ignition of the first catalytic reactor (2), whereafter combustion of the fuel/air mixture partly takes place in gas phase in an intermediary chamber (14) between the first catalytic reactor (2) and the second catalytic reactor (3).

2. A method according to claim 1, characterized in that the catalytic combustion, together with the gas phase combustion which is constituted by a flame, heats the end surface (17) of the second catalytic reactor (3) being closest to the first catalytic reactor (2) to a temperature which exceeds or is equal to the ignition temperature of the second catalytic reactor (3), i.e. the temperature at which a 50% conversion rate is obtained in the second catalytic reactor (3), whereafter the mass flow through the catalytic reactor (3) is adjusted so that substantially all combustion takes place in the second catalytic reactor (3) and combustion in the first catalytic reactor and in the gas phase substantially ceases.

3. A method according to claim 2,

c h a r a c t e r i z e d i n that all of the end surface (17) of the second catalytic reactor (3) being closest to the first catalytic reactor (2) is heated to a temperature which exceeds or is equal to the ignition temperature of the second catalytic reactor (3) before the mass flow through the catalytic reactor (3) is changed.

4. A method according to claim 1, 2 or 3, c h a r a c t e r i z e d i n that the first catalytic reactor (2) is pre-heated to its ignition temperature, whereafter the first catalytic reactor (2) is charged with a fuel/air-mixture having a λ-value exceeding 1, whereby catalytic combustion is started in the catalytic reactor (2) and whereby the temperature in the catalytic reactor (2) is caused to rise further above the ignition temperature, whereafter the λ-value is raised by increasing the air mass flow through the catalytic reactor at a catalytic reactor temperature corresponding to 60%-100% conversion in the catalytic reactor.

5. A method according to any one of the preceding claims, c h a r a c t e r i z e d i n that the gas phase combustion in the intermediary chamber (14) is achieved by increasing the mass flow through the first catalytic reactor (2) after ignition of the first catalytic reactor (2).

6. A method according to any one of the preceding claims, c h a r a c t e r i z e d i n that the first catalytic reactor (2) is electrically pre-heated.

7. A method according to any one of the preceding claims, c h a r a c t e r i z e d i n that the combustion in the first catalytic reactor (2) mainly takes place in the intermediary chamber (14) during ignition of the second catalytic reactor (3).

8. A catalytic combustor comprising a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), c h a r a c t e r i z e d i n that the ratio between the volume of the first catalytic reactor (2) and the volume of the second catalytic reactor (3) is 4.5×10^{-3} - 0.18 and preferably 0.016 - 0.05.

9. A catalytic combustor comprising a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), c h a r a c t e r i z e d i n that at least one of the catalytic reactors consists of a net.

10. A catalytic combustor in accordance with claim 8 or 9, c h a r a c t e r i z e d i n that a static mixer (10) is mounted upstream of the first catalytic reactor (2).

11. A catalytic combustor in accordance with claim 8, 9, or 10, c h a r a c t e r i z e d i n that a first flow-equalizing and mixing net (11) is mounted upstream of the first catalytic reactor (2).

12. A catalytic combustor in accordance with any one of claims 8-11, c h a r a c t e r i z e d i n that a second flow-equalizing net (12) is mounted between the first catalytic reactor (2) and the second catalytic reactor (3).

13. A catalytic combustor in accordance with any one of claims 8-12, c h a r a c t e r i z e d i n that it comprises an air blower (5) for supplying the combustor with air and that a conduit (19) for returning a part of the exhaust gas from the catalytic combustor to the air blower (5) is arranged downstream of the second catalytic reactor (3), between the catalytic reactor (3) and the air blower (5).

14. A catalytic combustor in accordance with any one of claims 8-13, c h a r a c t e r i z e d i n that a heat exchanger (20) through which the air to the air blower (5) may be conducted is arranged downstream of the second catalytic reactor (3).

15. A catalytic combustor in accordance with any one of claims 8-14, c h a r a c t e r i z e d i n that a Peltier element for retrieving electrical energy is arranged in connection with the second catalytic reactor (3).

16. A catalytic combustor in accordance with any one of claims 8-15, c h a r a c t e r i z e d i n that it is used for heating in a vehicle.

17. A method for controlling the ignition process of a catalytic reactor (2), wherein the catalytic reactor (2) is pre-heated to a temperature exceeding or equal to the ignition temperature of the catalytic reactor (2), i.e. the temperature at which a 50% conversion rate is reached in the catalytic reactor, c h a r a c t e r i z e d i n that mixture (8) of fuel and air having a λ-value exceeding 1 is introduced to the catalytic reactor (2) whereby catalytic combustion is started in the catalytic reactor (2) and whereby the temperature in the catalytic reactor (2) is caused to rise further above the ignition temperature, whereafter the λ-value is increased to a second λ-value, exceeding the initial λ-value, by increasing the mass flow through the catalytic reactor (2) at a temperature in the catalytic reactor (2) corresponding to 60%-100% conversion in the catalytic reactor.

19. A method according to claim 18, c h a r a c t e r i z e d i n that the initial λ-value is between 1 and 2 and the second λ-value is between 2 and 4.

20. A method for controlling the ignition process and the operation of a catalytic combustor comprising a catalytic reactor (2), c h a r a c t e r i z e d i n that the temperature and thereby the efficiency in the catalytic reactor is controlled by changing the λ-value for an air/fuel-mixture which is introduced into the combustor, wherein a lowering of the λ-value produces a higher temperature in the catalytic reactor and a rise in the λ-value produces a lower temperature.

21. A method according to claim 20, c h a r a c t e r i z e d i n that the combustor comprises a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2).

AMENDED CLAIMS

[received by the International Bureau on 4 December 1997 (04.12.97); original claims 1-4 and 7 amended; remaining claims unchanged (5 pages)]

1. A method of igniting and controlling a catalytic combustor (1), wherein the combustor comprises a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), wherein the first catalytic reactor (2) is heated to a temperature which exceeds or is equal to the ignition temperature of the first catalytic reactor (2), i.e. the temperature at which a 50% conversion rate is achieved in the catalytic reactor, whereafter a mixture of fuel and air is introduced to the first catalytic reactor (2), whereby catalytic combustion is started in the first catalytic reactor (2), characterized in that the mass flow through the catalytic combustor (1) is increased after ignition of the first catalytic reactor (2), whereby combustion of the fuel/air mixture partly takes place in gas phase in an intermediary chamber (14) between the first catalytic reactor (2) and the second catalytic reactor (3), and whereby the catalytic combustion, together with the gas phase combustion which is constituted by a flame, heats the end surface (17) of the second catalytic reactor (3) being closest to the first catalytic reactor (2) to a temperature which exceeds or is equal to the ignition temperature of the second catalytic reactor (3), i.e. the temperature at which a 50% conversion rate is obtained in the second catalytic reactor (3).

2. A method according to claim 1, characterized in that the mass flow through the catalytic reactor (3) is adjusted after ignition of the second catalytic reactor (3) so that substantially all combustion takes place in the second catalytic reactor (3) and combustion in the first catalytic reactor and in the gas phase substantially ceases.

3. A method according to claim 2,

c h a r a c t e r i z e d i n that all of the end surface (17) of the second catalytic reactor (3) being closest to the first catalytic reactor (2) is heated to a temperature which exceeds or is equal to the ignition temperature of the second catalytic reactor (3) before the mass flow through the second catalytic reactor (3) is changed.

4. A method according to claim 1, 2 or 3, c h a r a c t e r i z e d i n that the first catalytic reactor (2) is pre-heated to its ignition temperature, whereafter the first catalytic reactor (2) is charged with a fuel/air-mixture having a λ-value exceeding 1, whereby catalytic combustion is started in the catalytic reactor (2) and whereby the temperature in the catalytic reactor (2) is caused to rise further above the ignition temperature, whereafter the λ-value is raised by increasing the air mass flow through the catalytic reactor at a catalytic reactor temperature corresponding to 60%-100% conversion in the catalytic reactor, whereafter the mass flow is increased further at a constant λ-value, whereby a part of the combustion is transferred from the first catalytic reactor (2) and takes place in gas phase in a flame which is produced in the intermediary chamber (14) between the first catalytic reactor (2) and the second catalytic reactor (3).

5. A method according to any one of the preceding claims, c h a r a c t e r i z e d i n that the gas phase combustion in the intermediary chamber (14) is achieved by increasing the mass flow through the first catalytic reactor (2) after ignition of the first catalytic reactor (2).

6. A method according to any one of the preceding claims, c h a r a c t e r i z e d i n that the first catalytic reactor (2) is electrically pre-heated.

7. A method according to any one of the preceding claims, c h a r a c t e r i z e d i n that combustion upstream of the second catalytic reactor (3) mainly takes place in gas phase in the intermediary chamber (14) during ignition of the second catalytic reactor (3).

8. A catalytic combustor comprising a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), c h a r a c t e r i z e d i n that the ratio between the volume of the first catalytic reactor (2) and the volume of the second catalytic reactor (3) is 4.5×10^{-3} - 0.18 and preferably 0.016 - 0.05.

9. A catalytic combustor comprising a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2), c h a r a c t e r i z e d i n that at least one of the catalytic reactors consists of a net.

10. A catalytic combustor in accordance with claim 8 or 9, c h a r a c t e r i z e d i n that a static mixer (10) is mounted upstream of the first catalytic reactor (2).

11. A catalytic combustor in accordance with claim 8, 9, or 10, c h a r a c t e r i z e d i n that a first flow-equalizing and mixing net (11) is mounted upstream of the first catalytic reactor (2).

12. A catalytic combustor in accordance with any one of claims 8-11, c h a r a c t e r i z e d i n that a second flow-equalizing net (12) is mounted between the first catalytic reactor (2) and the second catalytic reactor (3).

13. A catalytic combustor in accordance with any one of claims 8-12, c h a r a c t e r i z e d i n that it

comprises an air blower (5) for supplying the combustor with air and that a conduit (19) for returning a part of the exhaust gas from the catalytic combustor to the air blower (5) is arranged downstream of the second catalytic reactor (3), between the catalytic reactor (3) and the air blower (5).

14. A catalytic combustor in accordance with any one of claims 8-13, characterized in that a heat exchanger (20) through which the air to the air blower (5) may be conducted is arranged downstream of the second catalytic reactor (3).

15. A catalytic combustor in accordance with any one of claims 8-14, characterized in that a Peltier element for retrieving electrical energy is arranged in connection with the second catalytic reactor (3).

16. A catalytic combustor in accordance with any one of claims 8-15, characterized in that it is used for heating in a vehicle.

17. A method for controlling the ignition process of a catalytic reactor (2), wherein the catalytic reactor (2) is pre-heated to a temperature exceeding or equal to the ignition temperature of the catalytic reactor (2), i.e. the temperature at which a 50% conversion rate is reached in the catalytic reactor, characterized in that mixture (8) of fuel and air having a λ-value exceeding 1 is introduced to the catalytic reactor (2) whereby catalytic combustion is started in the catalytic reactor (2) and whereby the temperature in the catalytic reactor (2) is caused to rise further above the ignition temperature, whereafter the λ-value is increased to a second λ-value, exceeding the initial λ-value, by increasing the mass flow through the catalytic reactor (2) at a temperature in the

catalytic reactor (2) corresponding to 60%-100% conversion in the catalytic reactor.

19. A method according to claim 18, c h a r a c t e r i z e d i n that the initial λ-value is between 1 and 2 and the second λ-value is between 2 and 4.

20. A method for controlling the ignition process and the operation of a catalytic combustor comprising a catalytic reactor (2), c h a r a c t e r i z e d i n that the temperature and thereby the efficiency in the catalytic reactor is controlled by changing the λ-value for an air/fuel-mixture which is introduced into the combustor, wherein a lowering of the λ-value produces a higher temperature in the catalytic reactor and a rise in the λ-value produces a lower temperature.

21. A method according to claim 21, c h a r a c t e r i z e d i n that the combustor comprises a first catalytic reactor (2) and at least a second catalytic reactor (3) arranged in series with the first catalytic reactor (2).

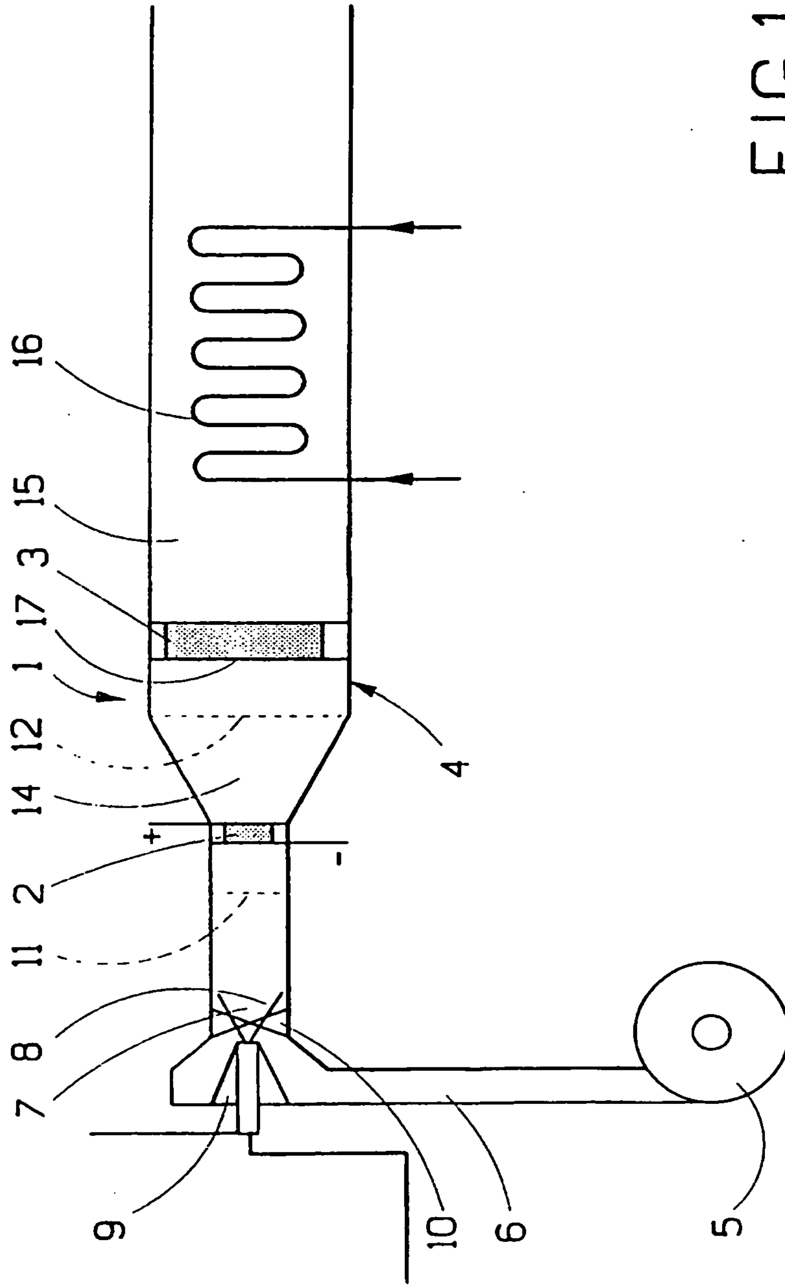

FIG.1

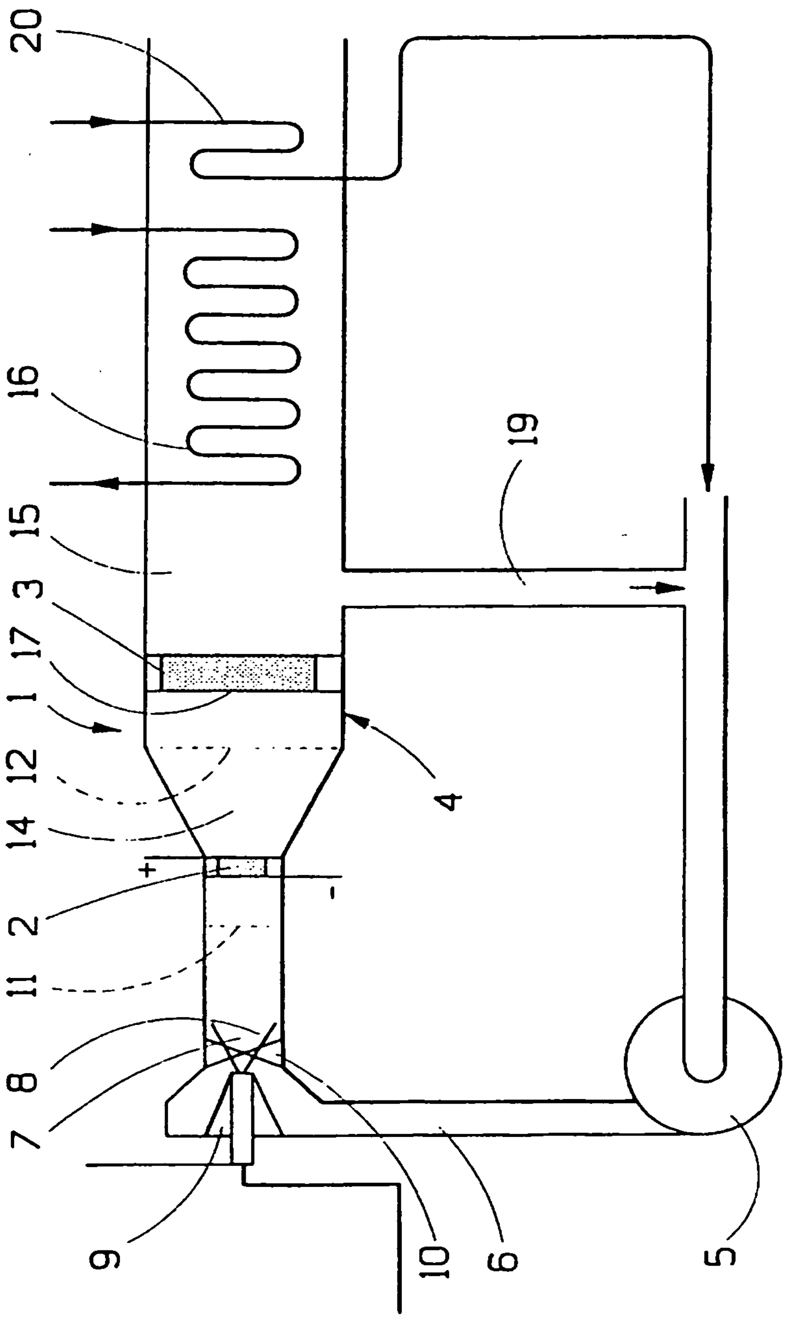

FIG.2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/01184

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: F23C 11/00, F23C 6/04, F23N 1/02, F23N 5/00, F23C 9/00, F02B 47/08
// F23Q 7/06, B60H 1/22, F23L 15/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: F23C, F23D, F23N, F23R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Patent Abstracts of Japan, Vol 11,No 10, M-552, abstract of JP,A,61-186704 (BABCOCK HITACHI K.K.), 20 August 1986 (20.08.86) --	1-5,7
X	Patent Abstracts of Japan, Vol 16,No 302, M-1275, abstract of JP,A,4-84009 (MATSUSHITA ELECTRIC IND CO LTD), 17 March 1992 (17.03.92) --	1-7
X	JP 61186704 A (BABCOCK HITACHI K.K.), 20 August 1986 (20.08.86) --	1-5,7

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" erlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 November 1997	20.11.97

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/01184

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SE 431669 B (ENGELHARD CORPORATION), 20 February 1984 (20.02.84), page 15, line 25 - page 16, line 9, figure 1	1,4,5,7
	--	
A	Patent Abstracts of Japan, Vol 18,No 183, M-1584, abstract of JP,A,5-340515 (MATSUSHITA ELECTRIC INC CO LTD), 21 December 1993 (21.12.93)	1-4
	--	
A	Patent Abstracts of Japan, Vol 13,No 591, M-913, abstract of JP,A,1-247902 (BABCOCK HITACHI K.K.), 3 October 1989 (03.10.89)	1
	--	

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See next page

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: 1-7

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

The application contains five independent claims, numbered 1, 8, 9, 18 and 20.

Claim 1 defines a method for ignition and control of a catalytic combustor comprising two catalysts which are connected in series. The method is characterised in that the first catalyst is heated to operating temperature, whereupon the flow of the mixture of fuel and air is increased so that gas phase combustion takes place in the space between the two catalysts.

Claim 8 defines a ratio between the volume of two catalysts which are connected in series. It is not mentioned that the smaller catalyst is used for heating the larger one. Even though it is obvious that the smaller of two otherwise identical catalysts is suitable for heating the larger one in a method according to claim 1, the ratio between the volumes has no primary relationship with the invention of claim 1.

Claim 9 specifies that one of the catalysts in series connection consists of a mesh. This has nothing to do with the method specified in claim 1. Since it is mentioned in the description that the word "volume" lacks meaning for mesh-type catalysts, claims 8 and 9 have no common technical features.

Claim 18 specifies a method for controlling the ignition of one single catalyst, in which the λ-value, when the catalyst has been heated, is increased to a level that permits operation with either complete or incomplete combustion (60% - 100% conversion). This method has no primary relationship with any of the previous independent claims, since a catalyst operating with incomplete combustion is a requirement for the invention of claim 1.

Claim 20 specifies a method for control of ignition and operation of one single catalyst, in which the temperature and "efficiency" of the catalyst is controlled by changing the λ-value. The claim does not mention that the catalyst should be operated with incomplete combustion, and this is not a requirement for the method. Therefore, this method has no primary relationship with the previous independent claims.

Consequently, the inventions specified in the five independent claims do not fulfil the requirements of unity of invention.

INTERNATIONAL SEARCH REPORT

Information on patent family members

01/10/97

International application No.
PCT/SE 97/01184

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 61186704 A	20/08/86	JP 1815577 C	18/01/94
		JP 5022802 B	30/03/93
SE 431669 B	20/02/84	CA 1003651 A	18/01/77
		DE 2235712 A,C	01/02/73
		FR 2146433 A,B	02/03/73
		GB 1395986 A	29/05/75
		SE 7714927 A	29/12/77
		US 3914090 A	21/10/75
		US 3928961 A	30/12/75
		US 3940923 A	02/03/76
		US 3982879 A	28/09/76
		US 4019316 A	26/04/77